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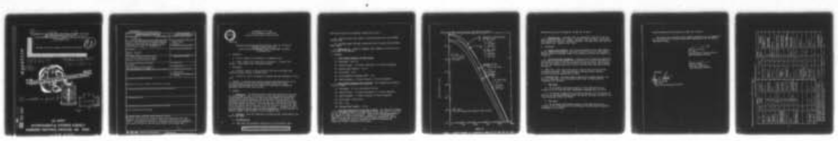

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22 SEPTEMBER 1977.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A special study of optical radiation hazards was performed on two light detection and ranging system lasers. Both lasers were Class IV high power lasers. The protection standard for intrabeam viewing could be exceeded out to a range of 9.9 km for the ruby laser and 210 m for the CO_2 laser.

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DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

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NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-0331-78
STANFORD RESEARCH INSTITUTE
LIGHT DETECTION AND RANGING (LIDAR) SYSTEM MARK IX LASERS
22 SEPTEMBER 1977

1. AUTHORITY.

a. AR 40-5, Health and Environment, 25 September 1974.

b. Letter, DRSEL-NV-SE, Night Vision Laboratory, 1 February 1977, subject: Laser Safety, and indorsements thereto.

2. REFERENCES.

a. AR 40-46, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, 6 February 1974.

b. TB MED 279, Control of Hazards to Health from Laser Radiation, 30 May 1975.

3. PURPOSE. To evaluate the potential hazards associated with the use of the light detection and ranging (LIDAR) system lasers and to make recommendations designed to limit exposure of personnel to potentially hazardous radiation from these devices.

4. GENERAL.

a. Background. The Stanford Research Institute (SRI) Mark IX ruby and CO_2 LIDAR system is used in experiments to take simultaneous multispectral transmissometer measurements and backscatter measurements to explore the relationships between propagation and the physical microstructure of the atmospheric aerosol during conditions of fog, rain, snow and military smoke. The system employs two lasers: one which operates in the visible, the ruby laser; and another vehicle operates in the far infrared, the CO_2 laser used to test effects at the far infrared laser wavelengths. Personnel of the US Army Environmental Hygiene Agency performed measurements of the LIDAR Mark IX system at Dugway Proving Ground, UT on 22 September 1977.

b. Inventory. Only one LIDAR Mark IX system had been constructed at the time of the study.

c. Instrumentation.

(1) EG&G Model 580 Radiometer System with Type 23A detector head.

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(2) Laser Precision Corp. Model RK 3230 energy meter with Type R108-2B detector head.

(3) Scientech Model 364 power energy meter with Scientech discalorimeter Model 360401.

d. Abbreviations. A table of commonly used radiometric terms and units is provided in the appendix.

5. FINDINGS.

a. Laser Output Parameters for Ruby System.

(1) Wavelength: 694.3 nm

(2) Radiant Energy: 1.0 J/pulse (specified) 0.5 J/pulse (measured)

(3) Emergent Beam Diameter: 2.0 cm

(4) Pulse Width: 30 ns

(5) Pulse Repetition Frequency (PRF): 1 Hz

(6) Beam Divergence: 0.5 mrad (focused), 1.8 mrad (unfocused)

b. Laser Output Parameters for CO_2 System. This system uses a Lumonics TEA-101-2 laser.

(1) Wavelength: 2.5 to 11 μm (used at 10.6 μm)

(2) Radiant Energy: 5.0 J/pulse (maximum), 0.7 J/pulse (measured)

(3) Beam Divergence: 1.2 mrad (focused), 2.3 mrad (unfocused)

(4) Pulse Width: 0.05 to 50 ns

(5) PRF: 1 Hz

(6) Emergent Beam Diameter: 2.5 cm

c. Beam Characteristics as a Function of Range. The protection standard (PS) for intrabeam viewing of a single pulse for the ruby laser is 0.5 μJ/cm^2 and for the CO_2 laser it is 10 mJ/cm^2. Beam radiant exposure measurements were taken at 1.0 km for both lasers; a reading of 12 μJ/cm^2/pulse was obtained for the ruby laser and 20 μJ/cm^2/pulse was obtained for the CO_2 laser. A theoretical plot of irradiance vs range with measured and theoretical values is provided in the Figure.

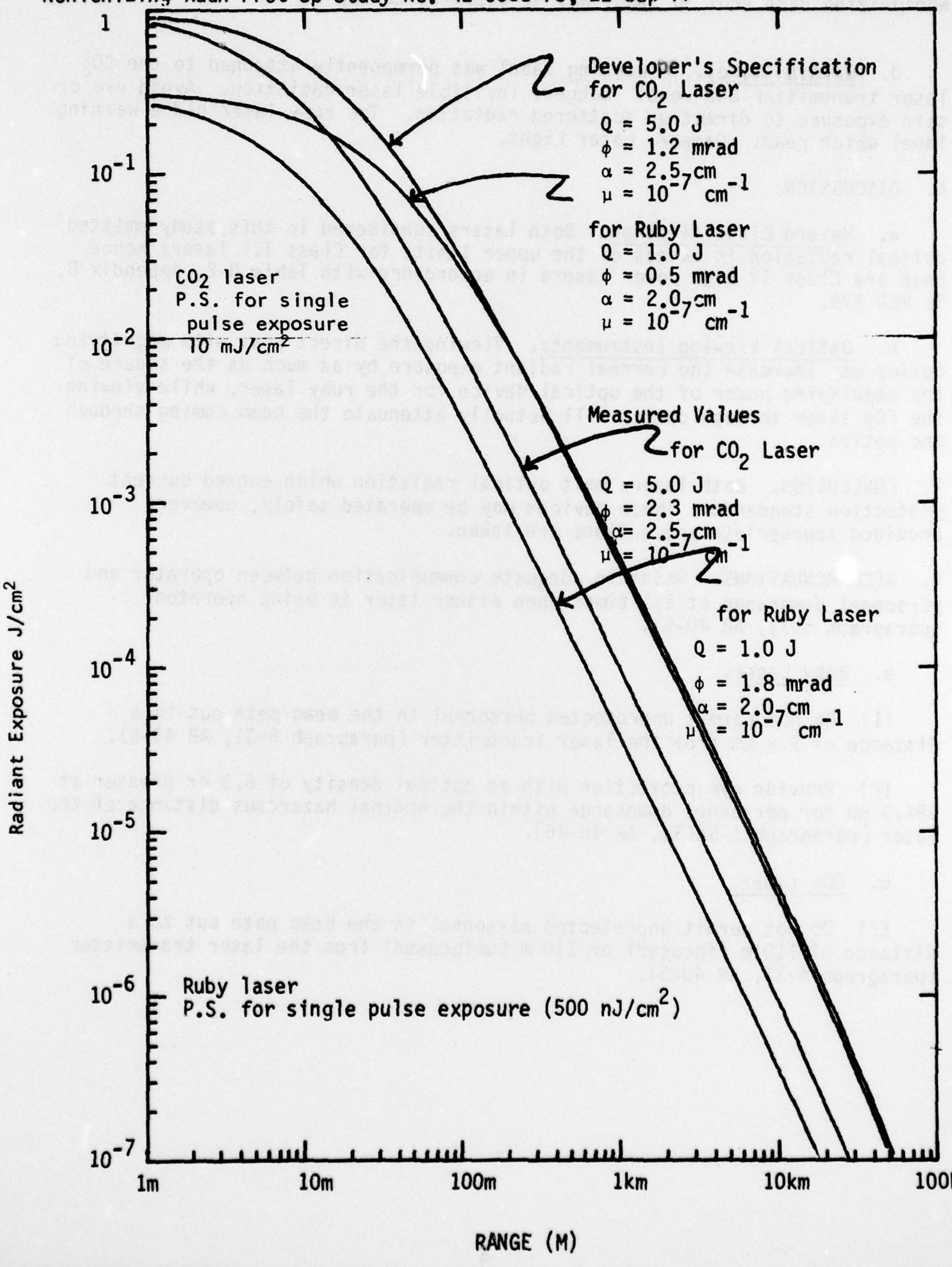

FIGURE 1. RADIANT EXPOSURE AS A FUNCTION OF RANGE FOR THE RUBY AND CO_2 LASER

d. Warning Label. A warning label was permanently attached to the CO_2 laser transmitter and read: Danger, invisible laser radiation. Avoid eye or skin exposure to direct or scattered radiation. The ruby laser had a warning label which read: Danger, Laser Light.

6. DISCUSSION.

a. Hazard Classification. Both lasers considered in this study emitted optical radiation in excess of the upper limits for Class III lasers hence both are Class IV high power lasers in accordance with Table B-2, Appendix B, TB MED 279.

b. Optical Viewing Instruments. Viewing the direct beam with magnifying optics may increase the corneal radiant exposure by as much as the square of the magnifying power of the optical device for the ruby laser, while viewing the CO_2 laser through optics will actually attenuate the beam coming through the optics.

7. CONCLUSION. Both lasers emit optical radiation which exceed current protection standards. These devices may be operated safely, however, provided appropriate precautions are taken.

8. RECOMMENDATIONS. Maintain adequate communication between operator and personnel downrange at all times when either laser is being operated (paragraph 5-31, AR 40-5).

a. Ruby Laser.

(1) Do not permit unprotected personnel in the beam path out to a distance of 9.9 km from the laser transmitter (paragraph 5-31, AR 40-5).

(2) Provide eye protection with an optical density of 6.3 or greater at 694.3 nm for personnel downrange within the nominal hazardous distance of the laser [paragraph 1-5d(3), AR 40-46].

b. CO_2 Laser.

(1) Do not permit unprotected personnel in the beam path out to a distance of 110 m (focused) or 210 m (unfocused) from the laser transmitter (paragraph 5-31, AR 40-5).

(2) Provide eye protection with an optical density of 2.7 or greater at far infrared (2.5 to 11.0 μm) for personnel downrange within the nominal hazardous distance.

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TABLE II

USEFUL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS[1,2]

RADIOMETRIC				PHOTOMETRIC			
Term	Symbol	Defining Equation	SI Unit and Abbreviation	Term	Symbol	Defining Equation	SI Units and Abbreviation
Radiant Energy	Q_e		Joule (J)	Quantity of Light	Q_v	$Q_v = \int \Phi_v dt$	lumen-second (lm·s) (talbot)
Radiant Energy Density	W_e	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter (J·m⁻³)	Luminous Energy Density	W_v	$W_v = \frac{dQ_v}{dV}$	talbot per square meter (lm·s·m⁻³)
Radiant Power (Radiant Flux)	Φ_e, P	$\Phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux	Φ_v	$\Phi_v = 680 \int \frac{d\Phi_e}{d\lambda} V(\lambda)\, d\lambda$	lumen (lm)
Radiant Exitance	M_e	$M_e = \frac{d\Phi_e}{dA} = \int L_e \cdot \cos\theta \cdot d\Omega$	Watt per square meter (W·m⁻²)	Luminous Exitance	M_v	$M_v = \frac{d\Phi_v}{dA} = \int L_v \cdot \cos\theta \cdot d\Omega$	lumen per square meter lm·m⁻²
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	E_e	$E_e = \frac{d\Phi_e}{dA}$	Watt per square meter (W·m⁻²)	Illuminance (luminous flux density)	E_v	$E_v = \frac{d\Phi_v}{dA}$	lumen per square meter (lm·m⁻²) lux (lx)
Radiant Intensity	I_e	$I_e = \frac{d\Phi_e}{d\Omega}$	Watt per steradian (W·sr⁻¹)	Luminous Intensity (candlepower)	I_v	$I_v = \frac{d\Phi_v}{dr}$	lumen per steradian (lm·sr) or candela (cd)
Radiance	L_e	$L_e = \frac{d^2\Phi_e}{d\Omega \cdot dA \cdot \cos\theta}$ [5]	Watt per steradian and per square meter (W·sr⁻¹·m⁻²)	Luminance	L_v	$L_v = \frac{d^2\Phi_e}{dr \cdot dA \cdot \cos\theta}$ [5]	candela per square meter (cd·m⁻¹)
Radiant Exposure (Dose, in Photobiology)	H_e	$H_e = \frac{dQ_e}{dA}$	Joule per square meter (J·m⁻²)	Light Exposure	H_v	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx·s)
				Luminous Efficacy (of radiation)	K	$K = \frac{\Phi_v}{\Phi_e}$	lumen per watt (lm·W⁻¹)
				Luminous Efficiency (of a broad band radiation)	$V(*)$	$V(*) = \frac{K}{K_m} = \frac{K}{680}$	unitless
Radiant Efficiency [3] (of a source)	η_e	$\eta_e = \frac{P}{P_i}$	unitless	Luminous Efficacy[3] (of a source)	η_v	$\eta_v = \frac{\Phi_v}{P_i}$	lumen per watt (lm·W⁻¹)
Optical Density [4]	D_e	$D_e = -\log_{10}\tau_e$	unitless	Optical Density[4]	D_v	$D_v = -\log_{10}\tau_v$	unitless
				Retinal Illuminance in Trolands	E_t	$E_t = \frac{L_v}{S_p}$	troland (td) = luminance in cd·m⁻² times pupil area in mm²

1. The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript λ. For example, spectral irradiance H_λ has units of W·m⁻²·m⁻¹ or more often, W·cm⁻²·nm⁻¹.
2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or μm are most commonly used to express wavelength.
3. P_i is electrical input power in watts.
4. τ is the transmission
5. At the source $L = \frac{dI}{dA \cdot \cos\theta}$ and at a receptor $L = \frac{dE}{d\Omega}$